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Running head: *Control Theory and Physical Activity*

An experimental test of control theory-based interventions for physical activity

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Abstract

Objectives: To provide an experimental test of control theory to promote physical activity.

Design: Parallel groups, simple randomized design with an equal chance of allocation to any group.

Methods: Participants not meeting recommended levels of physical activity but physically safe to do so (N = 124) were recruited on a UK university campus and randomized to goal-setting + self-monitoring + feedback (GS+SM+F, n = 40), goal setting + self-monitoring (GS+SM, n = 40) or goal-setting only (GS, n = 44) conditions that differentially tapped the key features of control theory. Accelerometers assessed physical activity (primary outcome) as well as self-report over a 7-day period directly before/after the start of the intervention.

Results: The participants in the GS+SM+F condition significantly outperformed the GS condition, d = .62, 95% CI d = 0.15 – 1.08, and marginally outperformed the GS+SM condition in terms of total physical activity at follow-up on the accelerometer measure, d = .33, 95% CI d = -0.13 – 0.78. The feedback manipulation (GS+SM+F *vs.* GS+SM and GS) was most effective when baseline intentions were weak. These patterns did not emerge on the self-report measure but, on the basis of this measure, the feedback manipulation increased the risk that participants coasted in relation to their goal in the first few days of the intervention period.

Conclusions: Using behaviour change techniques consistent with control theory can lead to significant short-term improvements on objectively assessed physical activity. Further research is needed to examine the underlying theoretical principles of the model.

Keywords: intervention; control theory; self-monitoring; goal-setting; feedback; physical activity

Control theory (Carver & Scheier, 1982) attempts to explain the processes underlying changes in behaviour. According to this theory, individuals monitor their current performance against a standard or goal. When discrepancies between one's current performance and the standard or goal arise, a negative feedback loop operates to minimise or remove the discrepancy. So, if an individual becomes aware that their current levels of physical activity fall below the set target or goal, the individual would be driven to increase their activity. She/he would then re-evaluate her/his latest performance against the goal which then influences future behaviour. Thus, according to control theory, key behaviour change techniques (BCTs) are goal-setting (to create a standard or goal within a hierarchy of control), self-monitoring (to monitor progress towards the reference value) and feedback (to illuminate any discrepancy between the set-goal and performance). If control theory is correct then delivering interventions that employ all of these key BCTs should bring about greater changes in behaviour including physical activity.

Reviews of the impact of specific BCTs on physical activity and diet demonstrate the value of self-monitoring of behaviour (e.g., Bartlett et al., 2014; Brannon & Cushing, 2015; Dombrowski, et al., 2012; Harkin et al., 2016; Henrich et al., 2015; Hill et al., 2013; Michie, Abraham, Whittington, McAteer, & Gupta, 2009; Michie et al., 2012; Olander et al., 2013; but see French et al., 2014). Broad reviews of BCTs have also provided support for goal-setting (Avery et al., 2012; Lara et al., 2014; Olander et al., 2013) and feedback (Henrich et al., 2015; Olander et al., 2013). However, to test the theory, the effect of combining these techniques should be examined.

In their review, Michie et al. (2009) reported that interventions comprising more BCTs derived from control theory were more effective than interventions that comprised fewer techniques derived from control theory. However, this analysis was conducted across studies rather than within a single study and thus is open to the risk of confounds. Michie et al. (2009)

also showed that combining self-monitoring with at least one other technique from control theory was significantly more effective than the other interventions in their review. These comparator interventions comprised those that used self-monitoring and no other behaviour change technique from Control Theory, interventions that used some of the techniques from Control Theory but not self-monitoring, as well as interventions that did not use any of the techniques from Control Theory. Thus, it is unclear from this review whether the other key BCTs from control theory (goal setting, feedback) explain additional variance in behaviour over and above self-monitoring alone.

Moreover, in the reviews related to physical activity, none of the included studies provided an experimental test of control theory. Specifically, none of the studies reported in the reviews by Michie et al. (2009) and Dombrowski et al. (2012) were explicitly based on control theory (see Prestwich et al., 2014). Similarly, for the studies included in the review by Hill et al. (2013), none of the included studies were explicitly based on control theory. The review by Brannon and Cushing (2015) did not specify the theoretical basis of the interventions included in their review, but these interventions did not specifically test the effects of combining goal-setting, self-monitoring and feedback.[1] Consequently, evidence suggests that basing an intervention on a single component of control theory (self-monitoring or goal-setting or feedback) can lead to greater health behaviour change but more rigorous tests of this theory for health behaviour change are needed.

Given the need for more tests of this theory, particularly using experimental designs (e.g. Prestwich, Webb, & Conner, 2015), and the fact that the theory makes clear the role of BCTs and the order they should be delivered (goal setting-monitoring-feedback) in a way which can be tested cumulatively, Control Theory was selected a-priori as the intervention base. The present research experimentally examined control theory by testing whether an intervention that manipulated all three key aspects of control theory (goal-setting + self-monitoring + feedback) was significantly more effective compared to interventions covering fewer aspects of the theory (goal-setting + self-monitoring only; goal-setting only). On the basis of the theory, and previous reviews (Dombrowski et al., 2012; Michie et al., 2009), it was predicted that participants allocated to the goal-setting + self-monitoring + feedback condition would increase their physical activity more than those allocated to the goal-setting only condition (hypothesis 1) and the goal-setting + self-monitoring only condition (hypothesis 2) who, in turn, would increase their physical activity more than those allocated to the goal-setting only condition (hypothesis 3).

To develop an understanding of those individuals who may benefit from these interventions, behavioural intentions and perceived behavioural control (PBC) were measured as potential moderators of the interventions. Individuals with weak behavioural intentions or PBC may be benefit least from monitoring and feedback because they should be more inclined to disengage or withdraw from the discrepancy reducing activity that attempts to minimise the gap between the current level of activity and the set goal (see Carver & Scheier, 1982, p. 121). However, those with stronger intentions and/or PBC might be more likely to achieve the set physical activity goal in any case and thus may benefit less than those with weaker intentions and/or PBC. Consequently, the moderating role of these variables was explored without directional hypotheses.

Testing theoretical principles

Given the role of the negative feedback loop in Control Theory, we also examined: 1) the risk of ‘coasting’ (i.e., the likelihood that participants on-track to meet their weekly goal the day before, failed to achieve 1/7th of the weekly goal the following day; 2) whether this risk differed depending on (a) whether participants were on track (i.e., ahead) or not (i.e., behind) to meet the weekly goal and (b) the self-monitoring group. Given the feedback manipulation makes more salient whether the participant is ahead vs. behind the set goal, those in the goal-setting + self-monitoring + feedback condition may be more at risk of coasting when they are ahead of the goal compared to those in the goal-setting + self-monitoring condition.

Method

One hundred and twenty-four university staff and students (91 women, 22 men, 11 not reported; mean age = 23.81 years (*SD* = 11.01 years); mean BMI = 22.76 (*SD* = 2.31)) were recruited on a University campus in northern England through an email distribution list. To be eligible for the study, participants had to report that they: (a) were not currently engaging in five or more 30 minute sessions of moderate intensity physical activity each week; (b) were not taking heart or blood pressure medication; (c) did not have a history of stroke or heart disease (including angina or heart surgery); (d) did not have a joint problem that may be aggravated by exercise. In addition, based on their reports of own height and weight, participants were excluded if their BMI did not fall within the 19-30 range. To reimburse them for their time, participants received £10 in vouchers after completing the study. Ethical approval was granted by a university departmental committee.

Design

Participants were randomly allocated to one of three conditions (goal-setting only [GS]; goal-setting+self-monitoring [GS+SM]; goal-setting+self-monitoring+feedback [GS+SM+F]) using simple randomization through a random number generator within a parallel groups design. As the allocation sequence was generated by the study website, it was concealed from the research team. Two researchers both recruited and tested participants in the initial session. These same researchers contacted participants during the study with standard text messages that differed for the experimental groups (reminding both groups to complete a daily diary) and the control group; consequently, they were not fully blinded to condition. Participants were unaware that there were different experimental conditions. The data analyst was not blinded to condition.

Procedure

In session 1 (Time 1: 0 weeks), participants followed a link to the study website. After answering eligibility questions and providing informed consent, participants supplied their mobile phone number in order to receive daily SMS text messages reminders (details provided below). Participants completed the Time 1 questionnaires which comprised the International Physical Activity Questionnaire (IPAQ; Craig et al., 2003) short-form and psychosocial measures and then read information about government physical activity guidelines but framed in terms of 600 activity units (AUs; actually MET-mins) explaining that moderate activities provide 4 AUs per minute and vigorous activity provides 8 AUs per minute.

All participants were then asked to try to achieve at least 600 AUs each week (86 AUs per day) and that moderate and vigorous activity could contribute to this target but low intensity activity, or any activity lasting less than 10 minutes, did not. Participants then completed the psychosocial measures. Participants were shown the accelerometer (Actigraph) and instructed to put it on when they woke up in the morning and to remove it before going to bed in the evening and when showering or swimming.

All participants received various text messages during the study. The number of text messages was the same for participants in all three conditions. Throughout the 2-week period of the study, all participants received a text message at 7am reminding them to wear their accelerometer and to note in a study diary when the accelerometer was worn. This message served as a prompt simply to wear the Actigraph rather than to self-monitor their physical activity given the Actigraph did not indicate physical activity levels to the participant.

One-week later (Time 2; 1 week), at 9am, participants were sent a link to the on-line Time 2 questionnaire (which took around 10mins). Later that same evening, the intervention began with participants receiving different information depending on the condition to which they were assigned (see Interventions section). At 8pm each day during the intervention period, a second daily text message was sent but the content of the message varied depending on the condition to which participants were randomised. While this second daily text message prompted those in the intervention conditions to self-monitor (see Intervention section), for those in the goal-setting only (GS) condition, the text messages simply reminded participants of the day of the study that they had reached. One week after completing the Time 2 questionnaire (Time 3; 2 weeks), participants re-visited the lab to complete the final Time 3 questionnaire and to return their Actigraph.

Interventions

All participants were asked, at both Time 1 and Time 2, to reach the same weekly target of 600 activity units (AUs). The target represented the Department of Health's (2004) recommendation of at least 30 minutes of moderate physical activity five times a week (4 METs (moderate activity) x 30 minutes x 5 days = 600). While this represented the only content for the goal-setting only (GS) condition, the goal-setting + self-monitoring (GS+SM) and goal-setting + self-monitoring + feedback (GS+SM+F) were given additional components.

Participants in the GS+SM and GS+SM+F conditions completed a daily self-monitoring measure (i.e., diary), adapted from the IPAQ short-form. Specifically, upon receiving a SMS text reminder at 8pm each evening during the intervention period (i.e., during the second week of the study), participants were required to visit the study website each evening to record how much physical activity they did that day. After reading the IPAQ's definitions of moderate and vigorous physical activity, participants were asked to record their responses, in minutes, to two items: “How much time did you spend doing vigorous physical activities like heavy lifting, digging, aerobics, or fast bicycling since you last logged on to our study website?” and “How much time did you spend doing moderate physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis since you last logged on to our study website?” Participants were also given the option to tick a box to indicate no moderate/vigorous activity.

In addition, participants in the GS+SM+F condition received feedback in the form of activity units based on their responses. This feedback included a ‘weekly target line’ showing participants how close they were to achieving the weekly target of 600 AUs and an explicit statement regarding whether they were ahead or behind the target (see Figure 1). This was based on the self-reported daily diary measure rather than the accelerometer data as the latter could not be analysed without the participant returning to the laboratory.

Measures

At all three time-points, physical activity and psychosocial constructs were assessed. Self-reported physical activity was measured via the IPAQ short-form. An objective measure of physical activity was obtained via GT3X Actigraphs worn by participants throughout the 2-week study. The ActiGraph has been validated against detailed self-report measures of physical activity (Sirard, Melanson, & Freedson, 2000) and other prominent accelerometer devices (see Welk, 2000). Actigraph data (total METs/week) from the first week reflected baseline activity, while data from the second week reflected post-intervention activity. Intentions in relation to the goal were measured reliably at all three time-points (all $\alpha > .91$) using two items (‘I intend to…’; ‘I will try to…’) requiring responses on a 7-point scale, ranging from [1] strongly disagree to [7] strongly agree. Perceived behavioural control in relation to the goal (PBC, all $\alpha > .81$) was also reliably measured (‘How much control do you have...?’; ‘If I wanted to, it would be easy for me to achieve...'; 'For me to achieve....is:') on 10-point scales (no control-complete control; strongly disagree-strongly agree; difficult-easy).

Results

One outlier was identified on the objective measure of physical activity (z = 3.23) and was subsequently removed from the analyses conducted on this measure.[2] The baseline characteristics of the participants within each condition are reported in Table 1. Univariate ANOVAs showed there were no differences across conditions in age, BMI, intentions or PBC (all p > .15). Moreover, during the baseline stage, before the materials differed across conditions, the level of objectively measured physical activity, $F(2, 111) = 0.17$, p = .85, and the self-reported level of physical activity taken just prior to the manipulation, $F(2, 84) = 1.41$, p = .25, did not differ across groups. Dropouts did not differ from completers on age, BMI or PBC (all p > .08) but dropouts (M = 5.66, SD = 1.48) reported weaker intentions at baseline than completers (M = 4.17, SD = 2.07). Dropout rates, across all time-points, did not differ across condition, $\chi^2(4) = 2.51$, p = .64 (pre-intervention: GS+SM+F = 5.0%; GS+SM = 2.5%; GS = 4.5%; post-intervention only one participant dropped out and this participant was allocated to the GS+SM+F condition). The flow of the participants is illustrated in Figure 2. Recruitment lasted a full year (February to February) and ended upon the conclusion of the funding period. No adverse events were reported.

METs: Objective measure

The levels of energy expenditure of the participants within each condition, after controlling for baseline energy expenditure levels, are reported in Table 2. ANCOVA, controlling for baseline total energy expenditure, revealed a significant main effect of condition on total energy expenditure post-manipulation, $F(2, 109)$=3.40, p = .04. Supporting hypothesis

1, LSD post-hoc tests revealed the GS+SM+F condition significantly outperformed the GS condition (p = .01; d = .62, 95% CI d = 0.15 – 1.08). Hypothesis 2 was not clearly supported given the GS+SM+F condition did not outperform the GS+SM condition at conventional levels of significance (p = .08, one-tailed; d = .33, 95% CI d = -0.13 – 0.78). There was no significant difference between the GS+SM and GS conditions (p = .22, d = .28, 95% CI d = -0.17 – 0.73). Thus hypothesis 3 was not supported.

Additional ANCOVA analyses were run for each type of physical activity, categorised based on MET values (<1 METs=sedentary; 1-3 METs=light activities; 3-6 METs=moderate activities; >6 METs = vigorous activities; see U.S. Department of Health & Human Services, 2008, p. 23). Within each of the specific bands of physical activity (<1 METs, 1-3, 3-6, and >6) analyses revealed that the energy expenditure varied across groups in the 1-3 MET, $F(2, 110) = 2.74$, p = .03, one-tailed, and 3-6 MET, $F(2, 109) = 2.56$, p = .04, one-tailed) ranges. Post-hoc tests revealed those in the GS+SM+F condition outperformed participants in the GS condition in the 1-3 METs (p = .02; d = .54, 95% CI d = 0.08 – 1.00) and 3-6 MET (p = .03; d = .52, 95% CI d = 0.06 – 0.98) ranges. Consequently, participants in the GS+SM+F condition expended less energy in the <1MET range compared to those in the GS condition (p = .05; d = -0.46, 95% CI d = 0.00 – -0.91).

Moderator analysis

Moderation analyses were conducted on the total energy expenditure dependent variable during the intervention period. One set of regression analyses entered baseline overall EE (MET-mins), feedback (yes/no), the proposed moderator (either intention or PBC) on the first step and the interaction term (feedback x proposed moderator) on the second step. The second set of moderation analyses replaced feedback with self-monitoring (yes/no).[3] Significant interactions were decomposed using simple slopes analyses. Specifically, the total energy expenditure during the intervention period was regressed on the predictor variable (i.e. feedback (yes/no)), controlling for baseline energy expenditure, at conditional values of the moderator: 1 *SD* above the mean; the mean; 1 *SD* below the mean.

The first set of regression analyses yielded a significant feedback x intention interaction, B = -274.43, SE = 111.42, p = .02, indicating that the effect of the feedback manipulation was moderated by the baseline measure of intention[4]. Specifically, feedback was effective when baseline intentions were weak, B = 703.56, SE = 230.46, p = .003, was marginally effective when baseline intentions were moderate, B = 296.38, SE = 165.90, p = .08, and was ineffective for those individuals with strong baseline intentions to do physical activity, B = -110.79, SE = 237.90, p = .64. This baseline measure of intentions did not moderate the effects of the self-monitoring manipulation (p = .10). Baseline measures of PBC did not moderate the effects of feedback (p = .53) or self-monitoring (p = .61).

IPAQ: Self-Report Measure

The above analyses were repeated using total METs based on responses to the IPAQ measure as the outcome. The IPAQ measure was scored and analysed in line with scoring recommendations (i.e., participants selecting ‘unsure’ regarding their walking, moderate or vigorous activities or reported doing in excess of 16 hours activity/day were removed from analyses; average durations of any type of activity (vigorous, moderate or walking) exceeding 3 hours/day were truncated to 3 hours and durations less than 10 minutes were recoded as 0 minutes). MET-minutes for this measure were calculated by multiplying minutes for walking by 3.3, minutes for moderate activities by 4 and minutes for vigorous activities by 8 before summing for each participant.

ANCOVA analyses, controlling for self-reported MET-minutes pre-intervention, indicated no difference in this measure at follow-up across the three groups, $F(2, 77) = 0.18$, $p = .83$. Comparing the groups within the three bands of activity (vigorous physical activity, moderate physical activity, walking) revealed no differences across the three groups either (all p's > .31). In the moderator analyses, neither the effect of the self-monitoring manipulation or the feedback manipulation on changes in self-reported MET minutes were moderated by intention or PBC (all p's > .26).

Testing theoretical principles

The risk of coasting and how this varied between participants ahead vs. behind the set goal as well as between those allocated to the GS+SM+F vs. GS+SM conditions are presented in Online Supplementary Table 2 (the method used to calculate the risk of coasting is explained under the table). The risk of coasting ranged from 21.4% to 100% across the various conditions and across each day.

The risk of coasting was slightly higher for those *behind* rather than ahead of the goal on each day though this reached or approached significance only on days 4, $\chi^2(1) = 4.19$, $p = .04$, and 7, $\chi^2(1) = 3.43$, $p = .06$, of the intervention period. When this comparison was made separately for participants in the GS+SM+F condition and participants in the GS+SM condition, the risk of coasting was lower for those ahead rather than behind the goal only for those in the GS+SM condition (day 4: $\chi^2(1) = 3.45$, $p = .06$; day 7: $\chi^2(1) = 4.09$, $p = .04$). Examining only those who were ahead of their goal and directly comparing those in the GS+SM+F vs. GS+SM conditions indicated that, towards the beginning of the intervention period, those in the GS+SM+F condition were at greater risk of coasting (day 2: $\chi^2(1) = 3.36$, $p = .07$; day 3: $\chi^2(1) = 3.71$, $p = .05$).

Discussion

The study presents a novel test which supports control theory. First, participants exposed to the most components of the model (goal-setting + self-monitoring + feedback noting the discrepancy between goal and performance) showed the highest activity levels at follow-up. Second, participants in this condition were still at risk of coasting towards their goal when they were ahead of schedule.

Several reviews have noted the benefits of BCTs aligned with control theory such as self-monitoring (e.g., Bartlett et al., 2014; Olander et al., 2013) and Michie et al. (2009) noted that interventions comprising more BCTs from control theory were more effective than those interventions that used less. The results of our study extends the work by Michie et al. (2009) as it clearly demonstrates that combining self-monitoring with feedback and goal-setting was more effective than goal-setting alone. In addition, given that Michie et al.'s analyses were conducted across studies, there are risks of bias associated with their review (e.g., methodological confounds) that are not applicable in the present study.

While there were between-group differences on the objective measure of physical activity, there was no parallel difference on the self-report measure. The lack of difference on the self-report measure may represent general insensitivity of the measure to detecting changes in physical activity across conditions (e.g., Prestwich et al., 2012) or could be related to the nature of the study. Specifically, participants involved in self-monitoring may pay attention to, and recall, different types of activity than those not engaged in self-monitoring thus confounding the self-report measure. Alternatively, given the objective measure assesses all physical activity including more automatically-driven activities, it could be that at least some effect of the manipulations operates automatically rather than purely through reflective processes.

The results suggested that while feedback on performance was useful for those with weak or moderate intentions pre-intervention, this technique did not increase physical activity for those who held strong intentions at baseline. While the lack of effect for the latter group could reflect a ceiling effect, the findings are still useful. First, should one want to develop an intervention tailored to specific psychological constructs then the results suggest that feedback on performance should be used for those with weak or moderate intentions; other BCTs would be more appropriate for those with strong intentions. Second, should one want to intervene on a specific or reduced number of participants (e.g., to minimise cost or time) using a feedback-based intervention, the results suggest that the resources should be directed to those with weak or moderate intentions. It should be noted, however, that the moderator analyses were exploratory in nature and thus require further research.

According to Control Theory, when individuals are behind their goal then they are driven to increase their efforts to minimise the discrepancy between one's current performance and target goal. Conversely, when they are ahead of their goal then they are at increased risk of coasting. In fact, participants in our study were less likely to achieve their daily goal on a specific day when they were behind the goal, as opposed to being ahead of the goal. While this may seem to be at odds with Control Theory, there are several possible reasons for this finding. In particular, those ahead of the target are likely to be more active and/or more concerned with meeting the set goal. In addition, although we set a physical activity goal, participants may already hold alternative physical activity goals (above or below the goal that we set within the experiment) as well as goals that may be in direct competition with the physical activity goal. The extent to which these apply for participants ahead or behind their goal may differ. Thus, the comparison between those ahead vs. behind the goal does not compare like with like. In addition, the rates of coasting were still quite high for those ahead of the goal, consistent with the underlying theory.

A cleaner comparison, due to randomization, assessed participants in the GS+SM+F condition versus those in the GS+SM condition. When ahead of their goal at the beginning of the intervention period, those in the GS+SM+F condition were at greater risk of coasting than those in the GS+SM condition. The difference between these two conditions was the provision of feedback in the form of an explicit statement of whether they were ahead/behind their goal and a figure representing their overall progress to the goal. The provision of this feedback should ensure the participants in the GS+SM+F condition were more aware of whether they were ahead/behind their target goal compared to those in the GS+SM condition. Interestingly this difference emerged at the beginning of the intervention period and diminished by the end of the intervention period. This may suggest that the feedback manipulation could lure participants into a position of security or overconfidence in meeting their goal which reduces when the deadline for meeting the goal draws nearer. However, the sample sizes within the cells used to make these comparisons were typically small and thus further research is needed to establish whether these initial trends are robust.

Further limitations of the study should be considered. First, the intervention period was brief but does offer an initial experimental test of the theory on physical activity, preferable to using correlational designs. Second, we did not conduct an a-priori sample size calculation due to the absence of a comparable study upon which to reliably estimate effect sizes. However, given a significant difference was detected on the primary outcome, including in sensitivity analyses taking into account the statistical outlier, the study was not underpowered to detect significant differences between the GS+SM+F vs. GS conditions but could be for the other comparisons. Third, the sample comprised university staff and students and dropouts had weaker intentions at baseline than those who completed the study limiting the generalizability of the findings. Fourth, the design did not include a full (no intervention) control condition. By including such a condition, we would have had the additional benefit of comparing the three intervention conditions against a no-intervention control. However, the key objective of the research was to examine the incremental effects of adding different components of control theory to an intervention. Thus, a major benefit of adding a no-intervention control condition to the current design would be to test the effect of goal-setting on physical activity an area in which has been extensively reviewed elsewhere (e.g., Olander et al., 2013). However, the proportion of people aware of physical activity guidelines has been reported to be around one-third (e.g., Bennett, Wolin, Puleo, Mâsse & Atienza, 2009). Thus, even with a no-intervention control group, there may be a reasonable proportion of this group with knowledge of a set-goal. Fifth, the nature of the interventions precluded tests of interactions between BCTs. For example, the nature of the feedback technique, particularly in the context of the 'discrepancy reducing feedback loop' articulated by Control Theory, necessitated a self-monitoring manipulation. Sixth, there may be concern that using accelerometers represents a self-monitoring tool. Michie et al. (2013), in their most recent taxonomy of BCTs, defined self-monitoring of behaviour as an approach to 'establish a method for the person to monitor and record their behaviour(s) as part of a behaviour change strategy' and noted that 'if monitoring is part of a data collection procedure rather than a strategy aimed at changing behaviour...' then it should not be coded as an instance of self-monitoring. Thus, simply asking participants to wear an accelerometer should be defined as a measure rather than a self-monitoring tool. Moreover, as the accelerometer did not provide any data visible to the participants, nor was it a feedback technique.

Given the limitations of the correlational tests of theories in the health area, further rigorous experimental tests like that reported here are needed (see Weinstein, 2007). This test demonstrates that basing a physical activity intervention more comprehensively on the underlying theory, in this case control theory, can lead to greater behaviour change.

Footnotes

[1]The lead author of the Olander et al. review has confirmed, via personal communication, that none of the studies in their review were explicitly based on control theory.

[2]The outlier came from the control group. Pulling the score of this participant into a *z*-score of 3.0 or including this participant in the analyses produced near identical results. Specifically, the comparison of the GS+SM+F vs. GS groups remained significant (both $p = .04$; vs. $p = .01$ in the original analyses) and the comparison of the GS+SM+F vs. GS+SM groups remained marginally significant (both $p = .09$, one-tailed; vs. $p = .08$, one-tailed in the original analyses). The univariate F's in both analyses were, however, weaker ($p = .06$, one-tailed, vs. $p = .04$ in the original analyses).

[3]The following variables were also assessed at the same time as intention and PBC and analysed as potential moderators: commitment, effort, planning (all with single items); self-efficacy; conscientiousness, Need for Cognition (NFC) and Consideration of Future Consequences (CFC) (see Online Supplementary Table 1). The items used to assess these constructs are available from the first author upon request.

[4]In further analyses, the intention items were combined with the effort and commitment items to create a broader construct assessing motivation. As with intention, the effect of feedback on energy expenditure was significantly moderated by motivation, $B = -294.91$, $SE = 133.27$, $\beta = -.60$, $p = .03$.

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Figure Captions.

Figure 1: Example of activity unit feedback given to participants in the GS+SM+F condition.

Figure 2: Participant Flow Diagram.

Table 1: Means (SD) of Baseline Characteristics Across Conditions

Condition	Age	BMI	Total Energy Expenditure[h]	IPAQ MET-Mins Pre-intervention	Intention (1-7)	PBC (1-10)
Goal Setting + Self-Monitoring + Feedback	25.03[c] (13.65)	23.24[d] (2.64)	13938.23[c] (1444.83)	2054.52 [f] (1390.46)	5.64[c] (1.51)	6.82[c] (1.69)
Goal-Setting + Self-Monitoring	23.47[c] (9.03)	22.45[c] (1.91)	14090.54 [a] (1177.93)	2859.12 [g] 1895.82	5.54[c] (1.63)	6.95[c] (2.14)
Goal-Setting	23.02[b] (10.15)	22.62[e] (2.34)	14082.96 [a] (1227.66)	2755.72 [d] 2077.47	5.56[b] (1.53)	7.57[b] (1.63)
Total	23.81 (11.01)	22.76 (2.31)	14039.85 (1274.69)	2606.00 1864.19	5.58 (1.54)	7.11 (1.88)

Note: [a] n=39; [b]n=41; [c]n=36; [d]n=34; [e]n=38; [f] n=23; [g]n=30; [h]Energy Expenditure noted as MET-mins per week (based on accelerometer)

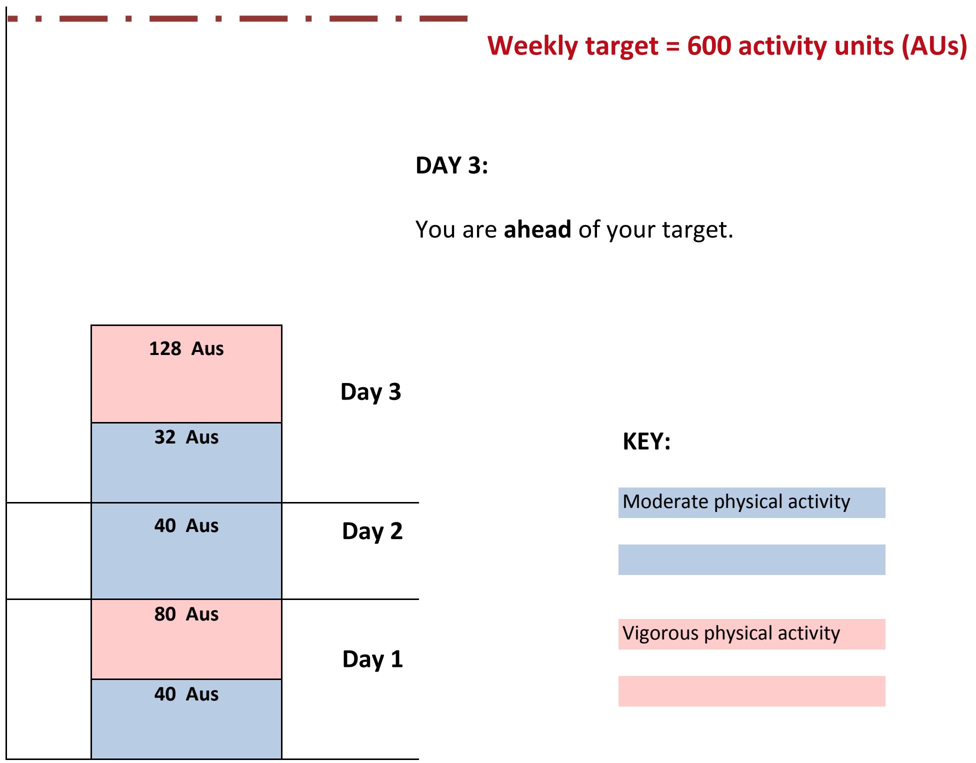
Table 2: Estimated Marginal Means Post-Intervention Physical Activity (Energy Expenditure noted as MET-mins per week) over 1-week controlling for Baseline Activity (SE)

Condition	<1 MET	1-3METs	3-6METs	>6METs	Total
Goal Setting + Self-Monitoring + Feedback	7385 (78.30)	3475 (106.45)	2821 (105.85)	480 (48.82)	14156 (136.31)
Goal-Setting + Self-Monitoring	7540 (75.26)	3243 (102.40)	2592 (101.57)	509 (46.90)	13891 (130.86)
Goal-Setting	7626 (76.25)	3114 (103.62)	2495 (102.79)	429 (47.50)	13661 (132.57)

Table 3: Summary of Moderation Analyses

Regression	Step	Predictor	B	SE	β	Notes
1	1	Baseline EE	.83	.06	.78***	Feedback sig. increased
		Feedback (yes/no)	309.36	170.09	.11†	EE for weak intenders,
		Intention	142.89	53.15	.16**	B = 703.56,
	2	Feedback (yes/no) x Intention	-274.43	111.42	-.57*	SE = 230.46, *p* = .003.
2	1	Baseline EE	.84	.06	.79***	SM sig. increased EE for
		Self-monitoring (yes/no)	277.44	165.49	.10†	weak intenders,
		Intention	142.24	53.27	.16**	B = 562.87,
	2	Self-monitoring (yes/no) x Intention	-188.67	110.88	-.42†	SE = 234.19, *p* = .02.
3	1	Baseline EE	.83	.07	.79***	
		Feedback (yes/no)	293.15	177.76	.10	
		PBC	-19.79	48.02	-.03	
	2	Feedback (yes/no) x PBC	45.08	100.63	.11	
4	1	Baseline EE	.84	.07	.79***	
		Self-monitoring (yes/no)	253.71	176.72	.09	
		PBC	-18.45	48.75	-.03	
	2	Self-monitoring (yes/no) x PBC	-70.91	120.26	-.20	

Note: † $p < .10$; *$p < .05$; **$p < .01$; ***$p < .001$



Weekly target = 600 activity units (AUs)
DAY 3:
You are **ahead** of your target.
128 Aus
32 Aus
Day 3
40 Aus
Day 2
80 Aus
40 Aus
Day 1
KEY:
Moderate physical activity
Vigorous physical activity

Figure 1.

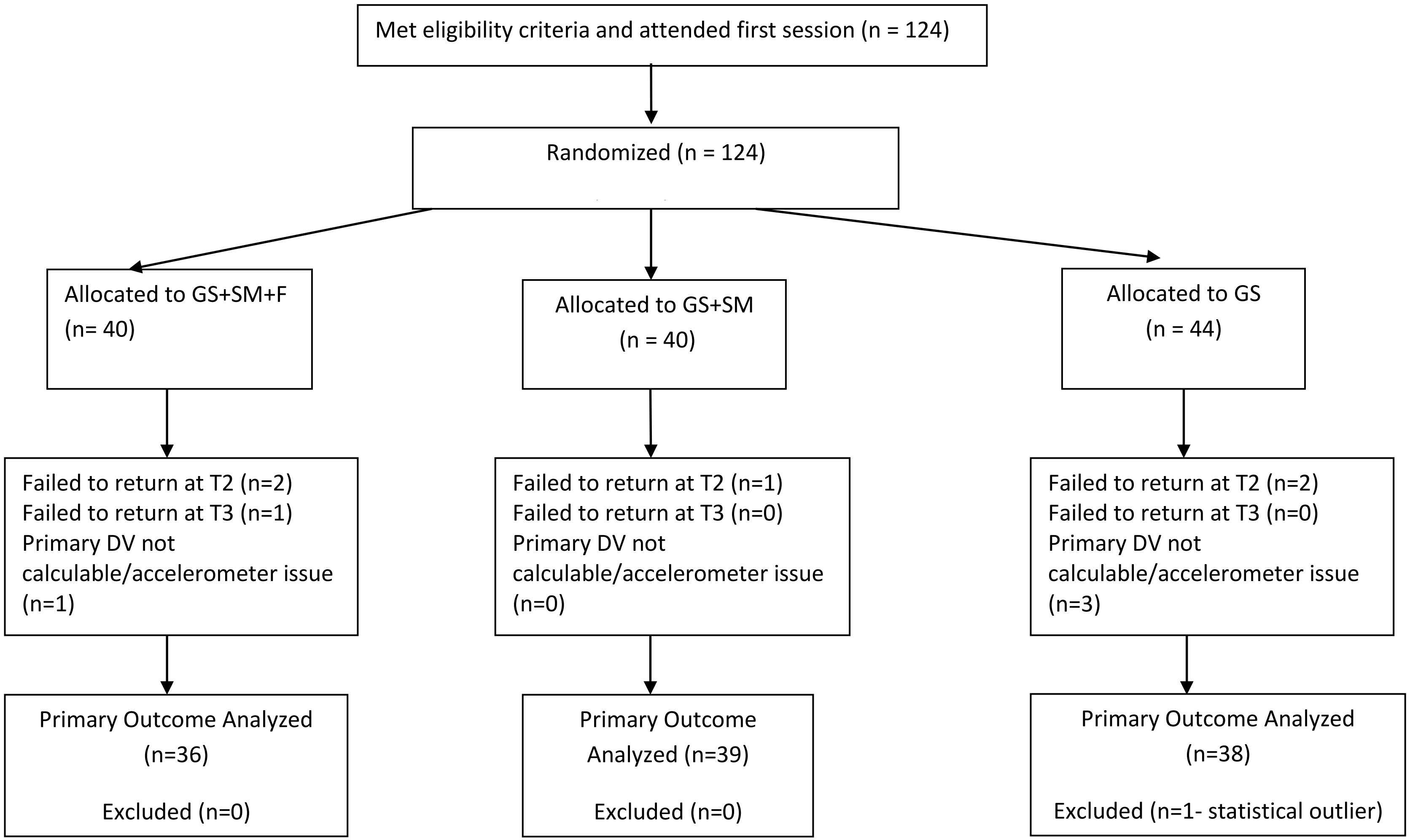

Met eligibility criteria and attended first session (n = 124)
Randomized (n = 124)
Allocated to GS+SM+F
(n= 40)
Allocated to GS+SM
(n = 40)
Allocated to GS
(n = 44)
Failed to return at T2 (n=2)
Failed to return at T3 (n=1)
Primary DV not calculable/accelerometer issue (n=1)
Failed to return at T2 (n=1)
Failed to return at T3 (n=0)
Primary DV not calculable/accelerometer issue (n=0)
Failed to return at T2 (n=2)
Failed to return at T3 (n=0)
Primary DV not calculable/accelerometer issue (n=3)
Primary Outcome Analyzed
(n=36)
Excluded (n=0)
Primary Outcome
Analyzed (n=39)
Excluded (n=0)
Primary Outcome Analyzed
(n=38)
Excluded (n=1- statistical outlier)

Figure 2.

Online Supplementary Table 1: Summary of Additional Moderation Analyses

Regression	Predictor	B	SE	β	Notes
5	Baseline EE	.80	.07	.76***	
	Feedback (yes/no)	354.51	174.07	.13*	
	Self-efficacy	134.69	73.63	.12†	
	Feedback (yes/no) x Self-efficacy	-53.07	188.25	-.10	
6	Baseline EE	.81	.07	.77***	
	Self-monitoring (yes/no)	310.77	169.95	.11†	
	Self-efficacy	135.44	74.04	.12†	
	Self-monitoring (yes/no) x Self-efficacy	-126.87	151.79	-.27	
7	Baseline EE	.83	.07	.78***	
	Feedback (yes/no)	295.32	174.31	.10†	
	Planning (single item)	76.66	52.71	.09	
	Feedback (yes/no) x Planning	-128.93	116.11	-.27	
8	Baseline EE	.83	.07	.78***	
	Self-monitoring (yes/no)	265.78	169.55	.10	
	Planning (single item)	76.60	52.82	.09	
	Self-monitoring (yes/no) x Planning	-124.16	108.60	-.28	

Regression	Predictor	B	SE	β	Notes
9	Baseline EE	.83	.07	.78***	Feedback sig. increased EE for those with low effort, *B*=629.41, *SE*= 238.89, *p* = .01.
	Feedback (yes/no)	305.65	173.83	.11†	
	Effort (single item)	88.26	52.06	.10†	
	Feedback (yes/no) x Effort	-217.36	111.72	-.46†	
10	Baseline EE	.83	.07	.78***	
	Self-monitoring (yes/no)	272.92	169.08	.10	
	Effort (single item)	87.13	52.16	.10†	
	Self-monitoring (yes/no) x Effort	-155.28	105.40	-.36	
11	Baseline EE	.83	.07	.78***	
	Feedback (yes/no)	310.39	177.88	.11†	
	Commitment (single item)	-.31	47.22	-.01	
	Feedback (yes/no) x Commitment	-62.45	114.46	-.17	
12	Baseline EE	.84	.07	.79***	
	Self-monitoring (yes/no)	270.05	171.91	.10	
	Commitment (single item)	-9.98	47.02	-.01	
	Self-monitoring (yes/no) x Commitment	-75.83	94.46	-.23	

Regression	Predictor	B	SE	β
13	Baseline EE	.82	.07	.78***
	Feedback (yes/no)	347.80	173.55	.13*
	NFC	7.34	123.91	.00
	Feedback (yes/no) x NFC	80.71	300.48	.10
14	Baseline EE	.83	.07	.78***
	Self-monitoring (yes/no)	298.02	174.72	.11†
	NFC	29.14	126.37	.02
	Self-monitoring (yes/no) x NFC	-237.21	257.54	-.32
15	Baseline EE	.82	.07	.78***
	Feedback (yes/no)	352.78	173.35	.13*
	Conscientiousness	-49.81	104.56	-.03
	Feedback (yes/no) x Conscientiousness	-63.65	237.81	-.08
16	Baseline EE	.83	.07	.78***
	Self-monitoring (yes/no)	289.92	171.82	.11†
	Conscientiousness	-32.45	104.99	-.02
	Self-monitoring (yes/no) x Conscientiousness	-23.53	217.19	-.03

Regression	Predictor	B	SE	β	Notes
17	Baseline EE	.82	.07	.78***	
	Feedback (yes/no)	348.69	173.99	.13*	
	CFC	10.98	119.23	.01	
	Feedback (yes/no) x CFC	-49.36	290.60	-.06	
18	Baseline EE	.83	.07	.78***	Self-monitoring sig. increased EE for those low in CFC (i.e., those focusing on immediate) *B*=609.85, *SE*=239.23, $p = .01$.
	Self-monitoring (yes/no)	290.57	172.13	.11†	
	CFC	-1.99	119.49	-.00	
	Self-monitoring (yes/no) x CFC	-459.25	242.24	-.59†	

Note: † $p < .10$; *$p < .05$; **$p < .01$; ***$p < .001$

Online Supplementary Table 2: Risk of 'coasting' in relation to set goal

	% Participants coasting in relation to 600 AUs/week (86 AUs/day) goal[a]					
	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
GS + SM + F and GS + SM groups						
Ahead of goal previous day	41.7%	36.4%	34.5%	42.9%	42.9%	26.9%
N (coasting/not coasting)	5/7	8/14	10/19	12/16	12/16	7/19
Behind goal previous day	75%	50%	75%	66.7%	50%	60%
N (coasting/not coasting)	3/1	6/6	6/2	6/3	4/4	6/4
Difference in coasting risk (ahead vs. behind goal)						
Chi-square	**1.33**	**0.60**	**4.19***	**1.55**	**0.13**	**3.43†**
GS + SM + F only						
Ahead of goal previous day	100%	62.5%	50%	37.5%	30%	22.2%
N (coasting/not coasting)	2/0	5/3	5/5	3/5	3/7	2/7
Behind goal previous day	66.7%	40%	75%	62.5%	50%	40%
N (coasting/not coasting)	2/1	2/3	3/1	5/3	3/3	2/3
Difference in coasting risk (ahead vs. behind goal)						

Chi-square	**0.83**	**0.63**	**0.73**	**1.00**	**0.64**	**0.50**
GS + SM only						
Ahead of goal previous day	30%	21.4%	35.7%	45%	50%	29.4%
N (coasting/not coasting)	3/7	3/11	5/14	9/11	9/9	5/12
Behind goal previous day	100%	57.1%	75%	100%	50%	80%
N (coasting/not coasting)	1/0	4/3	3/1	1/0	1/1	4/1
Difference in coasting risk (ahead vs. behind goal)						
Chi-square	**1.93**	**2.68**	**3.45†**	**1.16**	**0.00**	**4.09***
Difference in coasting risk (GS+SM+F vs. GS+SM groups: Ahead of goal participants)						
Chi-square	**3.36†**	**3.71†**	**1.63**	**0.13**	**1.05**	**0.16**
Difference in coasting risk (GS+SM+F vs. GS+SM groups: Behind goal participants)						
Chi-square	**0.44**	**0.34**	**0.00**	**0.56**	**0.00**	**1.67**

Note: *$p < .05$; † $p < .10$; [a]Percentage of participants failing to meet the 86 AUs/day goal on a specific day.
Please note that reported N's are lower than the number of participants allocated to the self-monitoring groups due to a number of reasons: a) technical issues meant the self-monitoring data could not always be matched up with other participant data; b) not all participants self-monitored every day; c) to be included in an analysis for a particular day, they had to have self-monitored their physical activity on that day and at least one day earlier in the week (to be able to calculate whether they were previously ahead/behind the goal, as well as their change in steps).

Classification of 'coasting' vs. 'not coasting'

- When participants recorded their physical activity on the specific day as well as their physical activity on the previous day, a participant classified as 'coasting' reported doing less than 86 MET-mins in the last day (a participant classified as 'not coasting' reported doing at least 86 MET-mins in the last day).

- When participants recorded their physical activity on the specific day but not on the previous day, a participant classified as 'coasting' reported doing less than 86 MET-mins on average since they submitted their last physical activity record (a participant classified as 'not coasting' reported doing at least 86 MET-mins on average since they submitted their last physical activity record).
- When participants did not record their physical activity on the specific day, they were excluded from the analysis for that particular day.